Determination of the Soil Water Retention Curve with Tensiometers

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Summary. An alternative technique for the determination of the soil water retention curve has recently been proposed whereby a tensiometer is used to measure soil suction and a balance to record the water content variations. The soil water retention curve is obtained by drying the soil either continuously or by stages (i.e. each drying stage is followed by an equalization period). Initial results from tests on compacted soil suggest that the relatively fast evaporation rate during continuous drying affects the water retention curve whereas the stage drying procedure provides more accurate results. Factors such as sample geometry and tensiometer position (relative to the sample) are also likely to affect the response obtained during continuous drying. These are the object of future investigation.

Key words: tensiometers, soil water retention curve

Introduction

Recently, high capacity tensiometers have emerged as an alternative instrument for the determination of the soil water retention curve because they provide fast measurements and determine directly the water tensile stress unlike instruments based on the axis translation.

Cunningham (2000), Toker et al. (2004) and Boso et al. (2003) determined the soil water retention curve by using an electronic balance to record the progressive decrease of water content in a sample left to dry to the atmosphere while using a tensiometer to measure the corresponding increase of suction. Boso et al. (2003) presented a comparison between stage drying and continuous drying for a sample of reconstituted clayey silt. The evaporation rate during continuous drying was slowed down by wrapping the sample in a geotextile. The results revealed no differences between the soil water retention curves determined using the two procedures. Cunningham (2000) investigated the influence of the evaporation rate for the continuous drying procedure applied to samples of reconstituted silty clay. In particular, he compared the soil water retention curves obtained by drying continuously the sample either to the atmosphere or inside a controlled humidity chamber. Similar results were obtained from the two procedures suggesting that the evaporation rate had little or no influence on the resulting soil water retention curve. These two studies also confirmed that tensiometers could be used to determine the soil water retention curve in a significantly shorter period of time in comparison to other conventional testing techniques (see also Toker et al. (2004)).

The stage drying procedure is expected to yield the most accurate results as the suction is measured after the sample has achieved equalization. On the other hand, continuous drying tends to be faster and simpler but it is likely to introduce inaccuracies due to the lack of equalization through the sample. These inaccuracies depend on factors such as sample size, shape, extent of surface exposed to drying and tensiometer position relative to the sample. Clearly, if the suction is measured on the surface of relatively large samples, the continuous drying procedure is expected to yield an incorrect water retention curve. Further study is therefore required to confirm the results obtained by Boso et al. (2003) and Cunningham (2000).

This paper presents some initial data from an experimental investigation on the particular drying procedure used (i.e. stage drying and continuous drying) for the determination of the soil water retention curve.

1 Experimental Set up

A sandy clay of intermediate plasticity with PL = 19.7%, LL = 43.3% and grain size distribution shown in Fig. 1 (Mendes 2006) has been used in this study. All samples were compacted according to the standard Proctor test at an initial water content of 25% (optimum water content is 18%).

The sample is enclosed in a metallic ring with a diameter of 100 mm and height of 30 mm and sealed by two (top and bottom) end plates, which include fittings to house tensiometers. The tensiometers used in this work have a nominal air entry value of 15 bar but they are capable of measuring suctions up to 1600 kPa (see Lourenço et al. (2006)). The water content decrease by the sample was measured by a digital balance logged into an acquisition system via a RS 232 interface.

For the case of stage drying, the soil water retention curve was determined by a sequence of independent drying phases and suction measurements on the same sample. For each stage, the soil was left to dry by evaporation to the atmosphere and, following an equalization period, the suction and sample mass were measured.

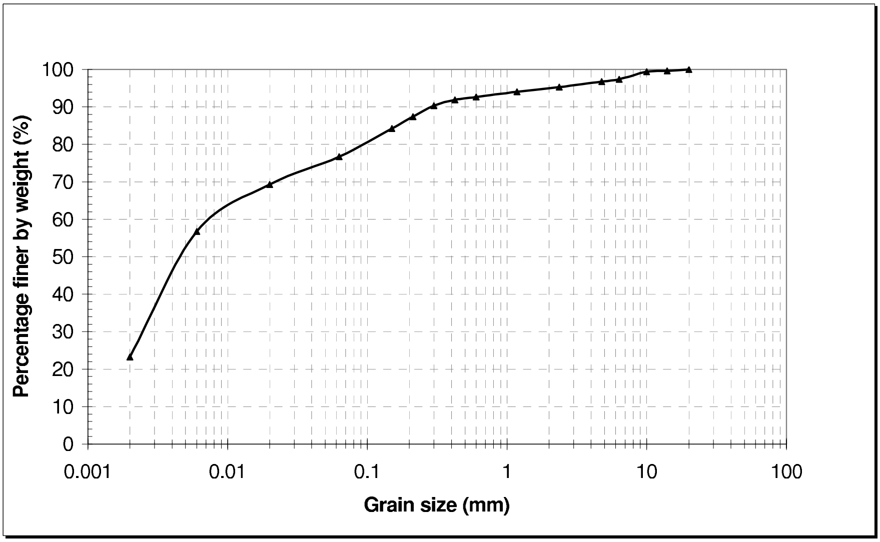

Fig. 1. Grain size distribution of the sandy clay soil (Mendes 2006)

The detailed procedure was as follows:

1) DRYING. The sample is dried by removing the top plate of the measuring cell and allowing the pore water to evaporate to the air for a set period of time. Drying was accelerated by a fan located above the sample;
2) EQUALIZATION. The top plate is placed back to seal the sample allowing water redistribution within the soil mass;
3) SUCTION MEASUREMENT. The tensiometer is inserted through the bottom plate in contact with the sample (a good contact is ensured by the own weight of the sample) and suction is continuously read;
4) MASS MEASUREMENT. After suction becomes constant indicating equalization, the total weight of cell, sample and tensiometer is recorded.

Steps 1) to 4) are repeated for the number of data points required to define the entire soil water retention curve. The above sequence is illustrated for one selected data point in Fig. 3.

For the continuous drying procedure, a sample with the same dimensions and initial conditions as for the stage drying was placed on the balance together with the metallic ring as shown in Fig. 2. A tensiometer was gently pushed into the top surface of the sample to a depth of approximately 3 mm. The entire length of the tensiometer cable was also supported to minimize any influence of its stiffness on the mass measurements. Pore water was left to evaporate through the exposed top surface of the sample while the decrease of water content and increase of suction were continuously recorded by the connected PC. The initial sample conditions and a summary of the key results for all six tests performed are shown in Table 1.

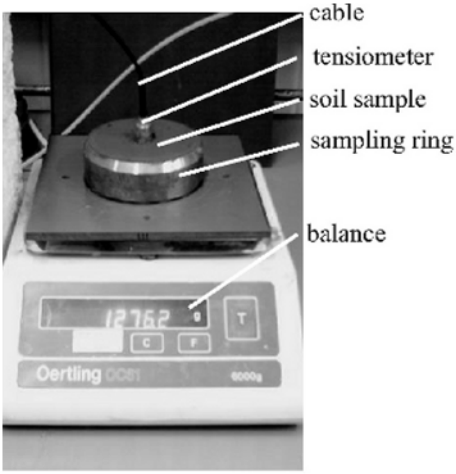

Fig. 2. Experimental set up for the continuous drying tests

Table 1. Initial and final physical indexes and summary of results

Test no.	Drying procedure	e_i	w_i [%]	w_f [%]	ΔM_w [g]	$s_{\max}$ [kPa]	Δt [h]
1	Stages	0.59	24.35	16.88	29.3	568.6	148.8
2		0.55	24.80	17.76	33.5	485.5	114.5
3		0.54	25.25	14.70	42.5	995.0	171.9
4	Continuous	0.52	24.70	18.37	26.0	376.0	25.1
5		0.56	24.76	17.25	30.0	745.2	32.5
6		0.55	24.17	17.23	27.9	584.6	28.44

e_i initial void ratio, w_i initial water content, w_f final water content, ΔM_w mass of water evaporated, $s_{\max}$ maximum suction of water retention curve, Δt test duration

2 Results

During all tests the soil significantly reduced in volume but such shrinkage was not measured. Therefore the corresponding variation of degree of saturation could not be calculated and the results are presented only in terms of gravimetric water content.

The entire test sequence for the definition of the soil water retention curve by using stage drying is shown in Fig. 3, which includes information of both gravimetric water content and suction for each of the nine drying stages. As expected, the suction equalizes at increasing values as the gravimetric water content decreases.

A similar set of information for a test performed by continuous drying is shown in Fig. 4, where suction and the gravimetric water content are plotted against the elapsed time. Inspection of Fig. 4 indicates that the decrease of the gravimetric water content was linear ($R^2 = 0.9993$) with respect to time confirming that the influence of the stiffness of the tensiometer cable on the mass measurement of the balance can be considered negligible. The analysis of Table 1 also indicates that the tests using continuous drying were about five times faster than the tests using the stage drying, with the entire water retention curve obtained in less than two days.

The soil water retention curves for all six tests performed are shown in Fig. 5. All curves show a similar pattern but they tend to diverge for increasing values of suction. Some curves in Fig. 5 end at lower values of suction due to premature cavitation of the tensiometer.

Discussion

Data presented in the paper revealed a partial agreement with Boso et al. (2003) and Cunningham (2000) results, which suggested that the drying rate had no influence on the soil water retention curve. Inspection of Fig. 5 indicates that the curves obtained by continuous drying are slightly displaced upwards with respect to the curves obtained by stage drying. In other words, the suction measured by continuous drying is higher than that measured by stage drying at the same water content. This may be explained by the inhomogeneous distribution of suction and water content through the sample in the former case, with faster drying of the sample surface with respect to the core. The

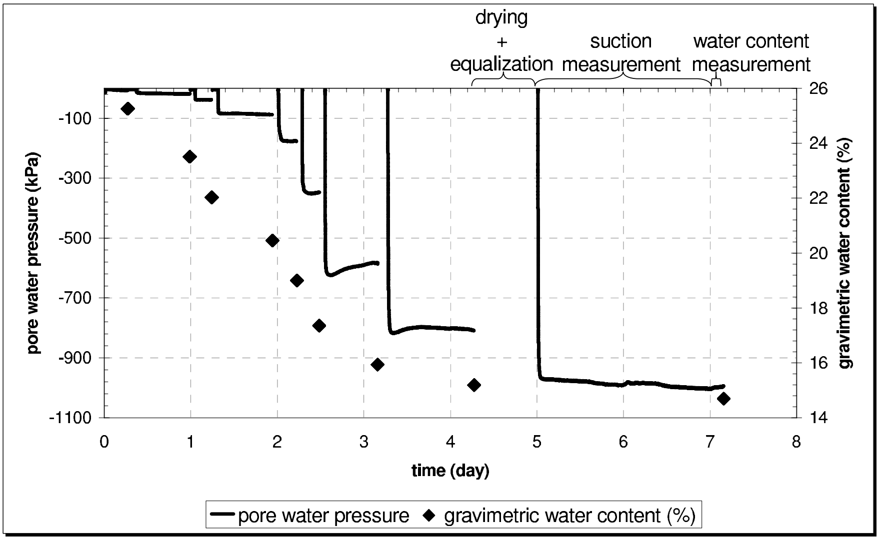

Fig. 3. Time sequence for the stage drying test 3, with the sequence of steps followed for each drying stage illustrated

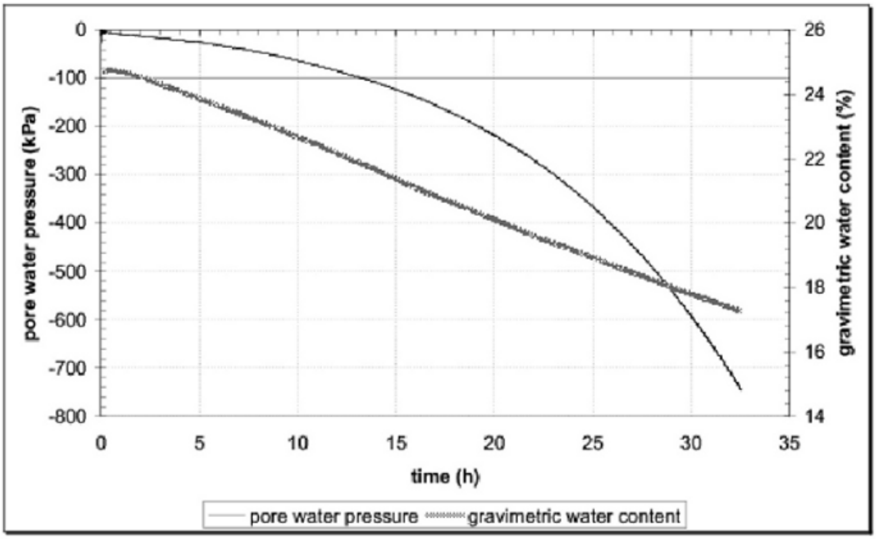

Fig. 4. Time sequence for the continuous drying test 5

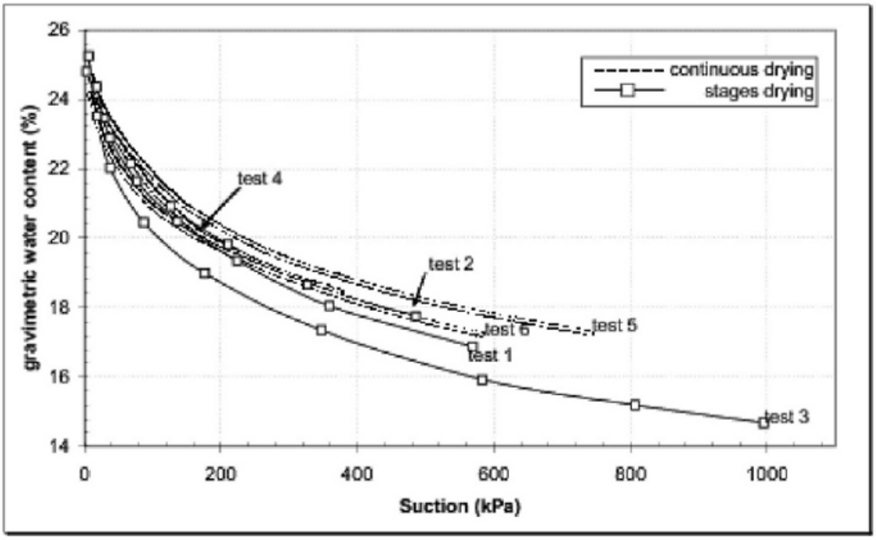

Fig. 5. All soil water retention curves

use of stage drying avoids such shortcoming and is therefore expected to yield more reliable results.

One limitation of both techniques is that volumetric measurements cannot be easily integrated in the experimental set up, preventing the determination of degree of saturation during the test (Toker et al. 2004).

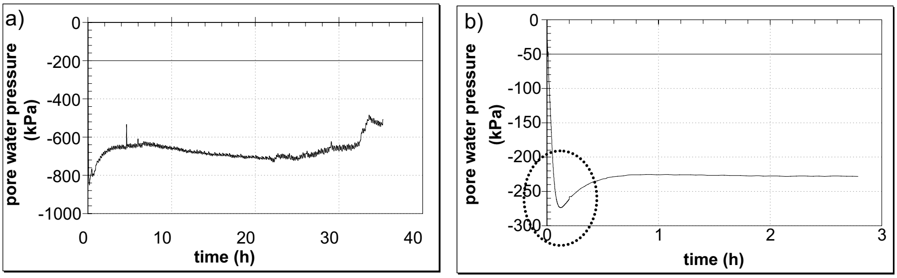

Fig. 6. Possible sources of error in the determination of the soil water retention curve by the stage drying procedure: **a**) poor contact of the tensiometer–soil interface and, **b**) insufficient equalization time

In the course of this study it was found that the following sources of errors had also a possible effect on the accurate measurement of suction and water content when using the stage drying procedure:

- When testing shrinkable soils, special care should be taken to ensure that the tensiometer remains in contact with the sample at all times during equalization of suction inside the measuring cell. In a preliminary test (Fig. 6**a**), the suction reading did not stabilize because the tensiometer was fixed to the top plate of the measuring cell and was, therefore, unable to follow the downward displacement of the soil sample as this shrunk. This problem was solved by moving the tensiometer to the bottom plate so that the sample's own weight was sufficient to ensure good contact of the soil with the probe.
- The gravimetric water content determination was affected by the low dry mass of the samples (approximately 400 g). For instance, an error of 2 g in the measurement of the mass of the dry sample would be enough to introduce an error in the water content of about 0.5%. It is possible that the scatter between the stage drying curves in Fig. 5 is due to the loss of little quantities of soil while opening and closing the measuring cell to let the sample dry out at the different water contents.
- For stage drying it is important to ensure achievement of equilibrium at the end of each stage. A suction rebound is sometimes observed after placing the tensiometer in contact with the soil, indicating lack of equalization (Fig. 6**b**). Hence, in order to avoid erroneous readings, enough time must be allowed for the stabilization of suction at a constant value.

Conclusions

The paper investigates the use of tensiometers for the determination of the soil water retention curve of a compacted sandy clay. The soil water retention curves determined by continuous drying show higher suctions than the curves obtained by stage drying at the same water content. The former procedure is probably affected by incomplete equalization of the sample whereas the latter is expected to yield the most reliable results. Possible factors affecting the accuracy of continuous drying are also discussed and areas of further investigation are identified.

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